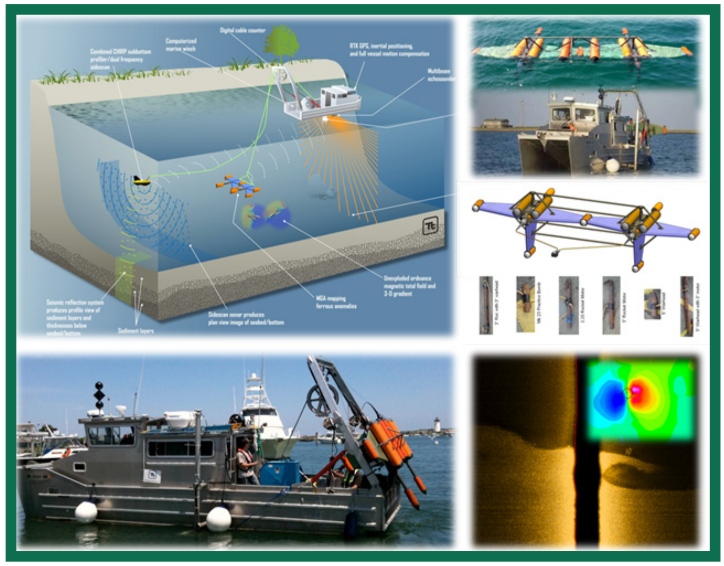
ESTCP
Cost and Performance Report

(MR-200808)



Wide Area Assessment (WAA) for Marine Munitions and Explosives of Concern

March 2012

ESTCP

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **MAY 2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Wide Area Assessment (WAA) for Marine Munitions and Explosives of Concern**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **ESTCP Office 4800 Mark Center Drive Suite 17D08 Alexandria, VA 22350-3605**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**51**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

COST & PERFORMANCE REPORT
Project: MR-200808

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ACRONYMS AND ABBREVIATIONS

2-D	two-dimensional
3-D	three-dimensional
AUV	autonomous underwater vehicle
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSM	conceptual site model
DoD	U.S. Department of Defense
ESTCP	Environmental Security Technology Certification Program
FS	feasibility study
GAPS	Global Acoustic Positioning System
GIS	geographic information system
GPS	Global Positioning System
Hz	hertz
IVS	instrument verification strip
kHz	kilohertz
kph	kilometer per hour
LiDAR	light detection and ranging
MBE	multibeam echosounder
MD	munitions debris
MEC	munitions and explosives of concern
MGA	Marine Gradiometer Array
mm	millimeter
MRU	motion reference unit
MTADS	Multisensor Towed Array Detection System
MTMGR	Moving Target Machine Gun Range
NAVD	North American Vertical Datum
nT	nanoTesla
QA	quality assurance
QC	quality control

ACRONYMS AND ABBREVIATIONS (continued)

RI	remedial investigation
ROV	remotely operated vehicle
RTK	real-time kinematic
SBP	sub-bottom profiler
Sq. km	square kilometer
SSS	sidescan sonar
TtEC	Tetra Tech EC, Inc.
USACE	U.S. Army Corps of Engineers
USBL	ultra-short baseline
UXO	unexploded ordnance
WAA	wide area assessment

ACKNOWLEDGEMENTS

In the performance of this project and preparation of this report document, we acknowledge the contributions of the following organizations and individuals:

Mr. Herb Nelson and Peter Knowles and the entire Environmental Security Technology Certification Program (ESTCP) for selecting, funding, and supporting the wide area assessment (WAA) for marine munitions and explosives of concern (MEC) throughout the demonstration effort.

The United States Army Corps of Engineers (USACE), including Carol Charette and Bob Selfridge, for allowing and coordinating for the use of the South Beach site for this demonstration.

Mr. Charles Blair, Harbor Master at the Edgartown Harbor on Martha's Vineyard, for allowing us to use his slip, for facilitating smooth logistics while on the Vineyard, and for that unforgettable tow back to port.

Dale McLure of Watercourse Construction for accepting advanced shipments and providing storage and a laydown area for our gear while on the Vineyard.

The Tetra Tech EC, Inc. (TtEC) demonstration crew of Ryan Cross, Lou Schwartz, Eric Taylor, Brain Corbett, Chris Burt, Blake Schwartz, and Ransom White, who met all the challenges we faced with solutions that led to our success.

TtEC also thanks Shirley Rieven, Mike Warminsky, and Patrick Fogleson of UXB and Tom Rancich of VRHabilis for providing recovered munitions items from the South Beach Site for our instrument verification strip (IVS) and for the diver installation of the IVS.

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1.0 EXECUTIVE SUMMARY

Well-developed standardized methodologies and approaches for assessment of terrestrial munitions and explosives of concern (MEC) exist; however, there are currently no standardized approaches for wide area assessment (WAA) of MEC in freshwater or marine environments.

The objective of this demonstration was to address the lack of a standardized approach for detecting and locating underwater MEC over large areas. To accomplish this objective, Tetra Tech EC, Inc. (TtEC) developed an approach utilizing multiple underwater detection and mapping technologies and instruments to acquire data sets, which were then used to evaluate ordnance-related conditions and geophysical features representing potential underwater MEC. The platform used for collecting magnetometer data was TtEC's Marine Gradiometer Array (MGA), which houses instrumentation demonstrated to be effective for the location and identification of MEC in marine or freshwater environments.

Quantitative and qualitative objectives were developed to assess system performance. These are briefly noted below along with the summarized results from the demonstration project.

- Demonstrate ability to detect underwater features of interest and measure the system's ability to effectively detect targets of interest with magnetic signatures representative of MEC at water depths from 0.5 to 35 meters (m).

  Results: The MGA met the data quality metrics as verified by instrument validation strip (IVS) results and was successful in all water depths (demonstrated at this and other sites).

- Demonstrate timely initial data processing and mapping and provide a qualitative and quantitative assessment of processing times for multibeam echosounder (MBE) data, which is needed to map site bathymetry, locate debris proud of the bottom, and guide MGA data acquisition.

  Results: Survey technicians were able to process the MBE data onboard the vessel and generate draft charts in near real time. On some survey days, MBE data were collected in the morning, processed, and then used in the afternoon to guide MGA data acquisition. TtEC considers this level of efficiency to be quite successful.

- Demonstrate good production rate—this is a measure of the system's capability to meet established hourly/daily production rates while meeting data quality objectives.

  Results: Quantitative goals set forth in the Work Plan, which were derived from previous experience and theoretical production rates based on survey speed and number of operational hours possible in a day, were met and exceeded. TtEC was able to exceed our projected MBE production rate by more than 50%.

- Demonstrate ease of use—this qualitative objective assesses the ease of implementing the WAA survey for both data collection and data processing.

  Results: Support vessel customization has resulted in a platform well-suited to conduct underwater MEC surveys anywhere in the continental United States

MGA data processing objectives were exceeded due in part to software development funded in part by the Department of Defense's (DoD) Environmental Security Technology Certification Program (ESTCP).

Using the MGA system to conduct WAA of MEC has several benefits:

- The MGA system is modular and can be disassembled and shipped via FedEx or other freight carrier to any location in the world.
- The modular configuration allows the system to be used in shallow (1 m and less), medium (1 m and up to 35 m), and deep water (35 m and up to 300 m) by altering the system's setup and tow method.
- The system has a rugged construction, with a weak link that allows for safe detachment from the tow cable while maintaining tracking with ultra-short baseline acoustic positioning system should the towfish contact the bottom. (Note: this functionality performed successfully during the demonstration project survey with no damage to towfish and only minutes of lost survey production.)
- The Overhauser magnetometers used in the MGA system have several advantages: (1) clear, strong proton precession signals using a very small amount of power; (2) very sensitive to changes in the geomagnetic field and not influenced by a phenomenon termed "heading error"; (3) sensor measurements are temperature independent, avoiding any system drift; and (4) simplified processing and data analysis due to eliminating correction for sensor drift, orientation, and heading error. In addition, the design of the MGA allows the total magnetic field for each magnetometer to be measured, as well as up to 10 two-dimensional magnetic gradients and 3 three-dimensional measured analytic signal vectors measurements. This system is unique in that it provides both total field and vector data.
- The MGA system is highly cost competitive with existing technologies when employed in combination with the data collection and processing tools and methods used in this demonstration project. This competitive cost is provided while detecting MEC over large areas and achieving reliable anomaly locations (approximately 89% of checks on IVS were located to within 2 m and approximately 47% were located within 1 m).

Overall, the WWA method using the MGA is shown to provide very accurate and low cost surveys of MEC in marine and freshwater environments than current methods.

2.0 INTRODUCTION

The DoD's ESTCP awarded a contract to TtEC to demonstrate an effective methodology for conducting WAAs for MEC in marine and freshwater environments. It is intended that this methodology can be used as a basis for standardizing methods for performing underwater MEC assessments. The ultimate goal was to develop standardized and effective data collection methods to acquire comprehensive, high-quality data for underwater MEC investigations.

2.1 BACKGROUND

More than 6 million terrestrial hectares of U.S. land are estimated to be impacted by MEC as a result of historical military operations. The underwater regions (marine and freshwater) impacted by MEC may be even larger. DoD is responsible for assessment and remediation of underwater areas impacted by MEC, but no standard approach for underwater WAA for MEC currently exists. In short, there are no industry standards for performing the assessment, no standard data collection systems, and no standard data processing techniques, and therefore no way to ensure consistency, comparability, and quality from project to project.

To develop a standardized methodology for underwater MEC work, it is necessary to identify the most effective and reliable technologies for MEC detection and classification. It is also critical to demonstrate that the selected technologies can be combined into a data collection system that can be deployed and obtain accurate and repeatable results. For this demonstration project, TtEC combined state-of-the-art survey technologies, including MGA, MBE, magnetometry, sidescan sonar (SSS), and sub-bottom profiling sonar (SBP). These technologies were coupled with positioning systems, including real-time kinematic (RTK) Global Positioning System (GPS), a motion reference unit (MRU) to measure vessel dynamics, and an ultra-short baseline (USBL) acoustic positioning system for underwater positioning of towed sensors. All these systems were mobilized aboard a research vessel and configured to function as a synergetic data collection system optimized for WAA of MEC. The systems aboard the survey vessel were monitored in real time to ensure consistent and accurate data acquisition.

2.2 OBJECTIVES OF THE DEMONSTRATION

The overall objective for this project was to demonstrate systems and methods for performing WAA for MEC in both marine and freshwater environments. The site selected for this demonstration was the former Moving Target Machine Gun Range (MTMGR) at South Beach, Martha's Vineyard, MA, hereafter referred to as South Beach (Section 5 provides site details).

The objectives for the WAA were to:

- Demonstrate the effectiveness of MGA at detecting and positioning seeded underwater MEC via an IVS.
- Demonstrate a practical approach to detecting and locating underwater MEC and munitions debris (MD) in real world conditions as part of a site investigation.
- Integrate supplemental sensor information with the gradiometer data ("data fusion") to aid in discriminating MEC from non-MEC in the underwater

environment, and use this supplemental sensor information to refine the conceptual site model (CSM).

2.3 REGULATORY DRIVERS

DoD has responsibility for assessment and cleanup of hundreds of historical in-water (marine and freshwater) munitions use sites (e.g., ranges, munitions piers, disposal sites) throughout the United States. A number of regulatory drivers may apply to munitions response sites, the two primary drivers being the Base Realignment and Closure Act and the Formerly Used Defense Sites Program. When former DoD property is transferred to non-DoD users, MEC assessment and cleanup operations fall under the compliance requirements of the Superfund (also known as Comprehensive Environmental Response, Compensation, and Liability Act [CERCLA]) statutes. Section 2908 of the 1993 Public Law 103-160, which requires that the work be performed in accordance with CERCLA provisions, centers on issues of assumption of liability for ordnance contamination on sites previously controlled by DoD. The technologies and system configurations demonstrated during this project begin the process of standardizing in-water MEC assessment and remediation methodologies for marine and freshwater sites. This work supports DoD in the development of CERCLA-compliant MEC remediation strategies for underwater areas.

3.0 TECHNOLOGY

This section provides an overview of the technologies employed in the demonstration project and an assessment of their advantages and limitations.

3.1 TECHNOLOGY/METHODOLOGY DESCRIPTION

A multifaceted approach was used to conduct surveys for marine MEC at South Beach. This approach included the use of acoustic imagery to aid in the location and identification of materials at least partially above the sediment surface and SBP data to evaluate subsurface stratigraphy and identify areas of sediment deposition where buried MEC items are likely. Lastly but most importantly, TtEC's MGA system was used to locate magnetic anomalies caused by ferrous debris on and below the sediment surface. The MGA comprises a three-dimensional (3-D) array of sensitive magnetometers and is capable of measuring the 3-D gradient of the magnetic field. The MGA is integrated with high accuracy RTK GPS and USBL positioning systems for the precise location of detected targets.

Table 1 contains a summary of the various technologies used, their land-based equivalent, and the purpose of their use. Figure 1 depicts the various sensors and positioning systems used for the South Beach demonstration, and Figure 2 presents an instrumentation configuration schematic. The survey system components for this project are described in detail in the following sections.

Table 1. Summary of technologies.

Technology	Terrestrial Equivalent	Purpose/Applications of Technologies
MBE	LiDAR	Used to map site bathymetry in high resolution. Allows identification of larger (approx. 0.5 m^2, depth dependent) cultural debris, as well as natural geomorphic features that pose a risk to the MGA while being flown at a low altitude.
MGA	Terrestrial/aerial magnetometer arrays	Measures magnetic field strength and 3-D magnetic field gradient that allows for the identification of anomalies that may be MEC.
SSS	Black and white aerial photography	Uses low grazing angle sonar beams that create shadows used to identify smaller items proud of the bottom. Higher frequency and closer proximity to the bottom increases the quality of the bottom image.
SBP	Seismic reflection	Used to evaluate stratigraphy and locate areas of sediment deposition where buried MEC items may be present. Aids in the identification of the sediment/bedrock interface, which is the maximum depth to which MEC items may be buried.
Positioning equipment	Terrestrial positioning equipment	Two components: RTK GPS and MRU, for positioning the vessel and measuring vessel motion; USBL for underwater acoustic positioning.

LiDAR – light detection and ranging

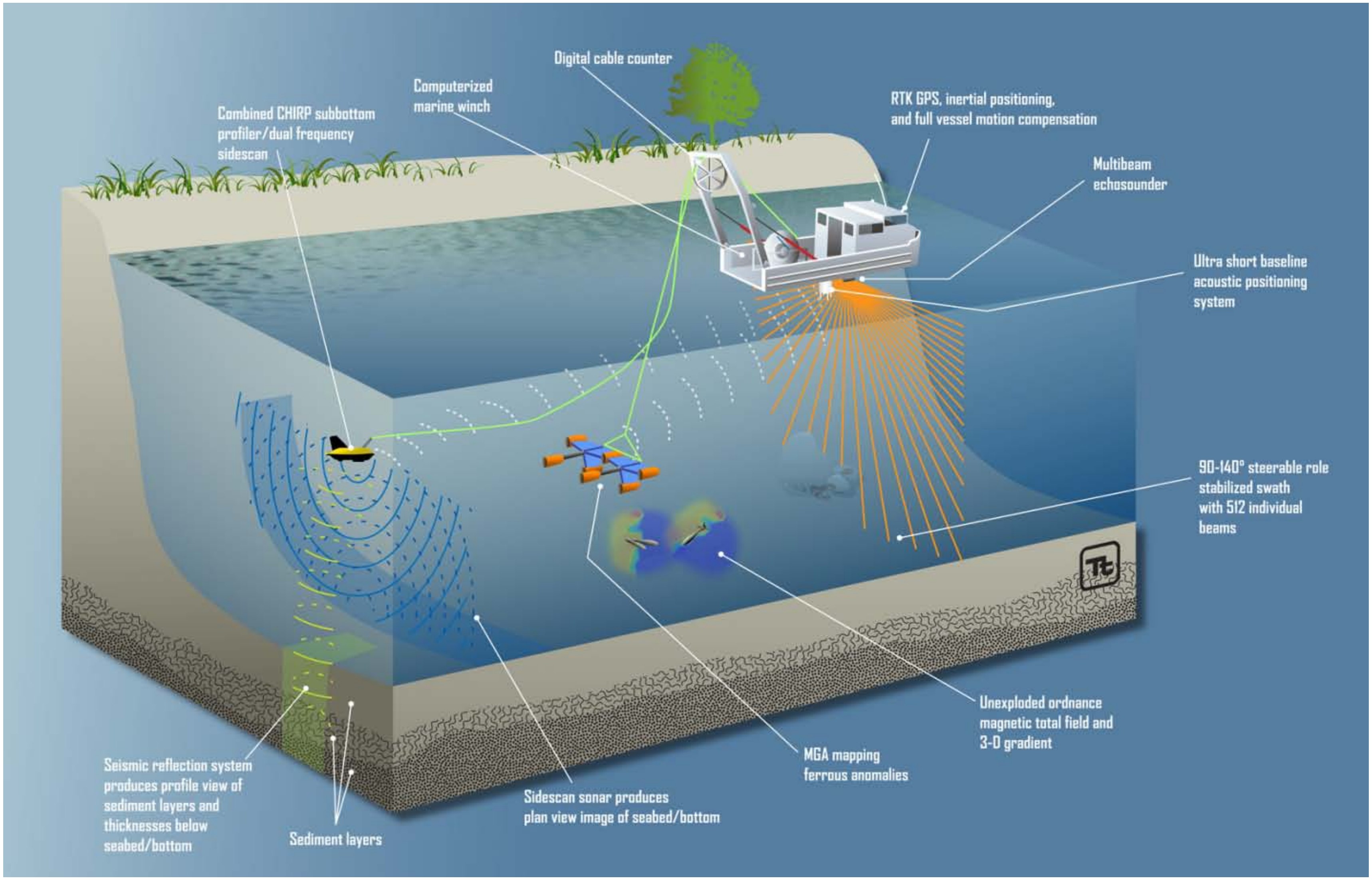

Figure 1. WAA survey system deployed at South Beach.

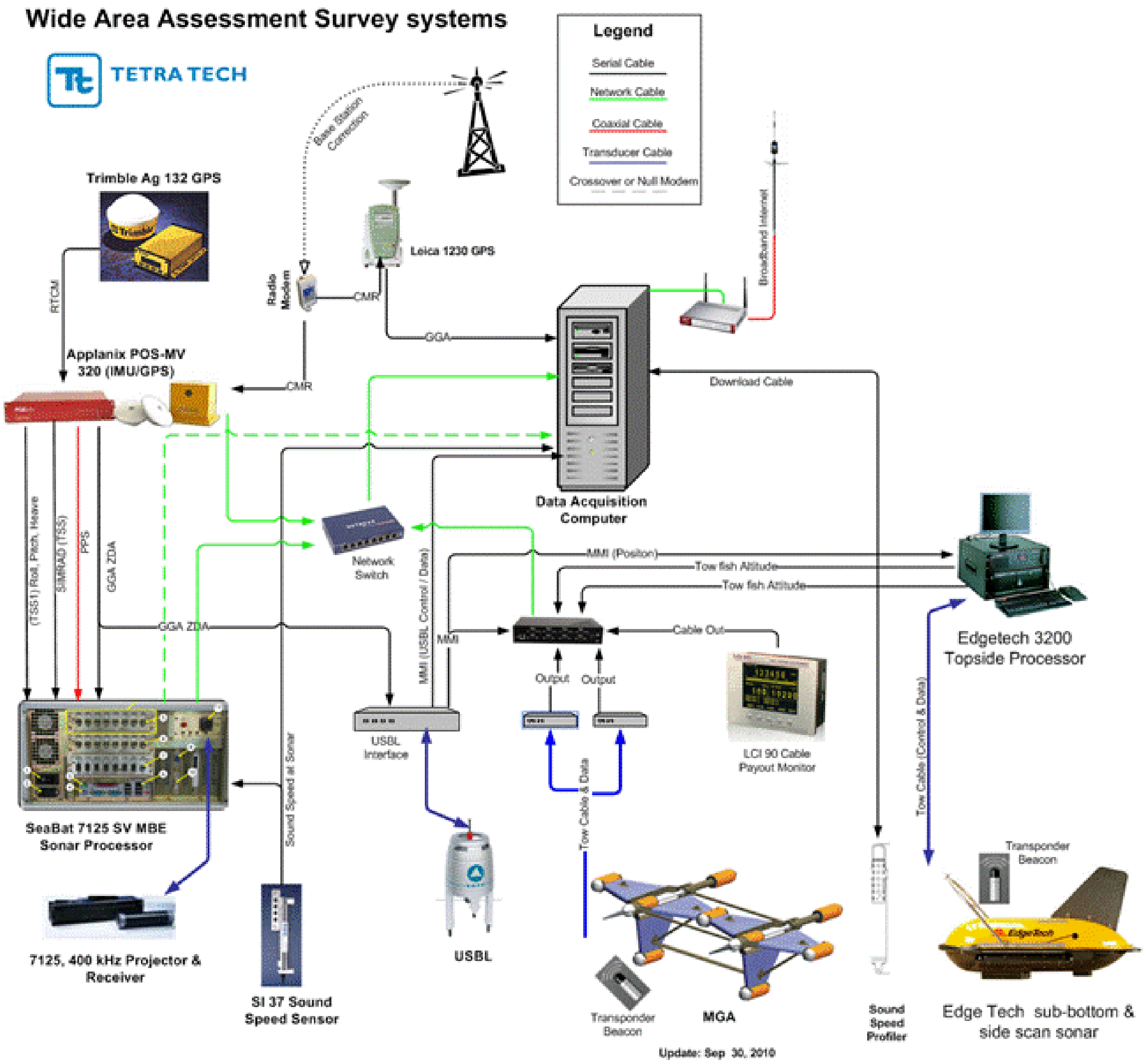

Figure 2. WAA survey systems.

3.1.1 High-Resolution Multibeam Echosounder

Prior to conducting MGA survey operations, TtEC collected high-resolution MBE data at the site. Details on the MBE survey can be found in the demonstration report (TtEC, 2011).

3.1.2 Marine Gradiometer Array

The MGA system, designed by TtEC, combined a gradiometer with support sensors to accurately detect and locate magnetic targets on and below the sediment surface. A two-gradiometer module, consisting of seven magnetometers with a swath width of 4 m, was used for this demonstration (Figure 3). The MGA is reconfigurable, allowing individual magnetometers to be removed or reoriented. The addition of floats or weights allows the MGA to operate in water depths from about 1 m (floated) to 300 m. The MGA measures the ambient magnetic field using a phenomenon called the Overhauser effect.

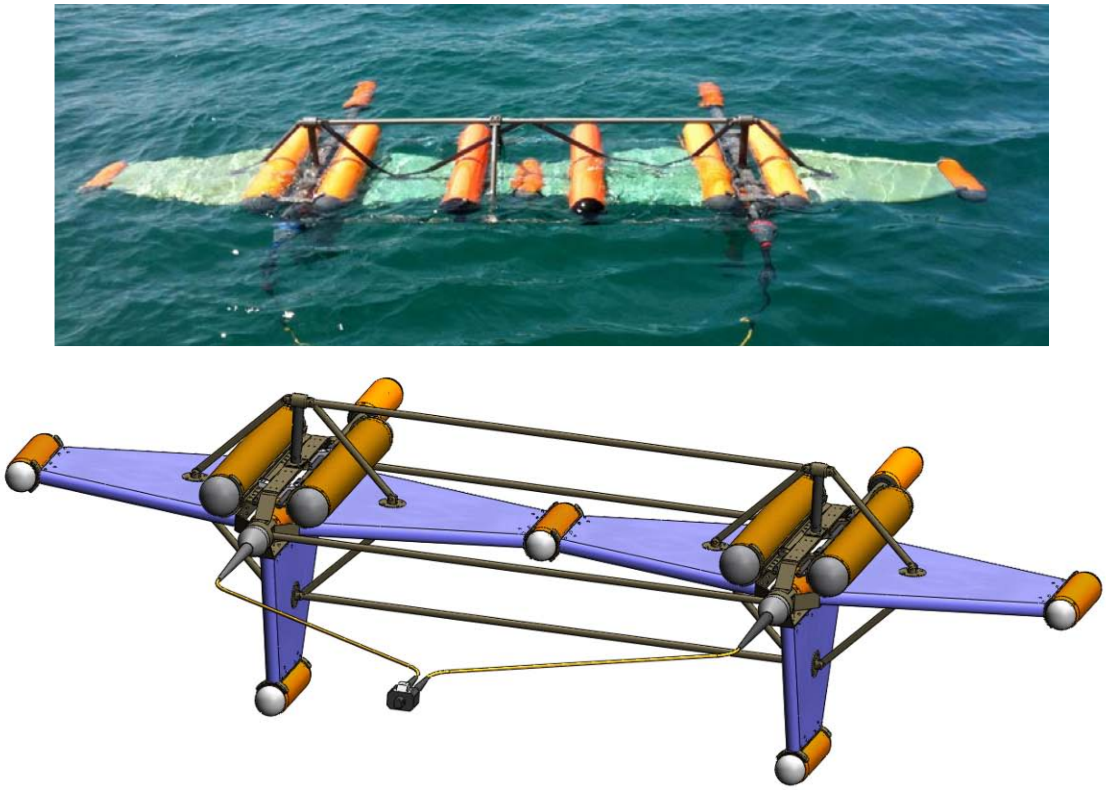

Figure 3. MGA configured for the South Beach survey with seven magnetometers.

The design of the MGA allows the total magnetic field for each magnetometer to be measured, as well as up to 10 two-dimensional (2-D) magnetic gradients and three 3-D measured analytic signal vectors that are automatically calculated in real time from the total field and gradient measurements. This system is unique in that it provides both total field and vector data.

Underwater positioning of the MGA was achieved using an IXSEA Global Acoustic Positioning System (GAPS) USBL acoustic tracking system and an electronic cable counter. The USBL system is more accurate than the cable counter and was the primary method for tracking the MGA. The GAPS USBL system used for this survey has an accuracy of 0.2% of the slant range, a level of performance unmatched by any other USBL system.

3.1.3 Sidescan Sonar

To provide high-quality imagery and to augment the MBE data, high-resolution SSS data were collected with an EdgeTech 2000-DSS combination SSS and SBP towfish with a 100/600 kilohertz (kHz) dual frequency CHIRP SSS. Details on the SSS survey can be found in the demonstration report (TtEC, 2011).

3.1.4 Sub-Bottom Profiler

Sub-bottom profiler data were collected to provide information on sediment type and stratigraphy in the surveyed areas. The system used to acquire SBP data was the EdgeTech 2000-DSS combination SSS and SBP towfish with a 2 to 16 kHz sub-bottom profiler. Details on the SBP survey can be found in the demonstration report (TtEC, 2011).

3.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

3.2.1 Advantages

The WAA approach developed by TtEC for underwater MEC WAA combines true 3-D analytic signal measurements from the MGA with data from other advanced survey instrumentation and high-accuracy vessel and towfish positioning to provide high-accuracy MEC detection. The survey system used for this project has several advantages over existing systems:

- The MGA is unique in that it measures both total field and vector data and accurately measures 3-D magnetic gradients, rather than 2-D gradients collected by other systems. The measurement of 3-D gradients over 2-D reduces background environmental noise from the dataset, reducing the number of false positives while retaining high sensitivity for detecting small (e.g., full 20 millimeter [mm]/40mm round) MEC and providing highly accurate positioning of anomalies.

Example total field data for a single 20mm round from the IVS detected within 0.5 m of the seeded location

- Positioning of the MGA and other in water systems is provided by a high-accuracy USBL positioning system that has an accuracy of 0.2% of the slant range.
- The TtEC MGA system was successfully deployed and operated in up to sea state 3 conditions. This is higher than any other known MEC detection platforms thus far.
- The TtEC WAA approach integrates magnetometer data with acoustic survey data. The MBE, SSS, and SBP provide valuable data for discerning the pattern of magnetic anomalies and assessment of in-water MEC sites. In some cases the acoustic data can provide additional information about a specific target such as whether the target is buried or the shape of the target.

3.2.2 Limitations

The limitations of the WAA system are the limitations of the individual technologies. For instance, all magnetometer operations are limited when working in locations with complex

geology or in close proximity to large ferrous bodies such as bridges or piers or when working near high-voltage electrical sources. Since the MGA measures gradients, it can in some cases compensate for these large and undesirable magnetic field sources.

Thus far, the MGA has been tested in water depths up to 35 m; however, it is rated to 300 m and could be modified for work in water up to 6000 m deep. TtEC expects that terrain following will become proportionally more difficult as depths increase, which will in turn require an increased flight height, automated flight capabilities, and/or integration into an autonomous underwater vehicle (AUV).

As depth increases, so do the inaccuracies of USBL positioning, although sub-meter accuracy should be retained up to survey depths exceeding 100 m.

For the demonstration survey, all required systems were mobilized on the R/V Ugle Duckling. While this vessel outperforms the survey platforms utilized by other underwater MEC detection surveys funded by ESTCP, it does have an operational sea state limitation (sea state 4). Fortunately, all components of our WAA survey are capable of operation in higher sea states and are easily mobilized to a larger research vessel when operations in greater sea state are required.

4.0 PERFORMANCE OBJECTIVES

The qualitative performance standard for this project was to demonstrate a practical approach to conducting WAA for MEC surveys in marine and freshwater environments. Since there was not a specific problem to solve during this demonstration project (e.g., reduce false positives, improve detection probability), the quantitative performance objectives were based on observed and anticipated system capabilities rather than specific parameters. Although meeting the identified quantitative performance goals for individual system components did not ensure the success of the demonstration, it did ensure that system components were functioning within their performance specifications. In addition, the application of data quality objectives ensured that high-quality data were obtained, which provided a sound basis for measuring the success of the demonstration.

Success of the demonstration was also determined by the ability of the WAA to locate and delineate features of interest at the project site. The features of interest for a munitions response site are typically munitions use areas such as impact areas (ranges), range safety fans, or disposal areas identified by developing a CSM based on historical data. At this project site, aerial bombing targets, range safety fans, and potential disposal sites have been identified in the CSM, which is discussed in more detail in Section 6. The performance objective was to demonstrate a practical method for effectively detecting underwater MEC, particularly over a wide area. Specifically, the MGA needed to detect targets with magnetic signatures representative of those generated by real MEC at water depths ranging from 1 to 120 ft (0.3 to 37 m). Table 2 lists the identified performance objectives for the demonstration along with the data needed to evaluate successful achievement of the objectives.

Table 2. Performance objectives.

Performance Objective	Metric	Data Required	Success Criteria	Results
Quantitative Performance Objectives				
Detection of underwater features of interest potentially representing MEC	System functionality	• Data from all systems over the IVS • Data from all systems at the demonstration site • Target dig list • Data from the diver investigation • IVS items list with coordinates	• Instruments detect all representative items in IVS. • Instrumentation meets quality goals identified in Table 3-2 of the demonstration report (TtEC, 2011). • Features of interest are observable in data. • All systems perform reliably (no data dropouts, equipment malfunctions).	• The MGA detected all representative items placed in the IVS, including many smaller munitions. Larger items were identified in the SSS; no IVS items mapped with MBE. • Instrumentation met the quality goals identified in Table 3-2 of the demonstration report (TtEC, 2011). • At the demonstration site, ferrous objects were detected with the MGA but most were not seen with the SSS. • After the initial shake-down, all survey/detection systems performed with minimal breakdown, with the exception of mechanical failures on the survey vessel. • Diver-based target verification data from the site were not available at the time of this report.
Timely initial data processing and mapping	Creation of draft data products (processed image data) for MBE and MGA data, mosaics for SSS, vertical imagery curtains for SBP	• Raw MBE soundings • Raw MGA data files • Raw SSS files • Raw SBP data	• Near real-time on board and preliminary post-processing of all data within 2 days of collection	• Preliminary post processing of MGA, SSS, and SBP data was complete within 1 to 2 days of collection. • MBE data were processed in near real-time on the vessel.
Good production rate	Number of line kilometers (km) of data collection per day	• Log of field work and all data files time tagged or stamped	• MGA: ~16 line km/day (approximately 3.5 acres/hr; 15-20 acres per day) • MBE : ~ 32 line km/day • SSS/SBP: ~ 32 line km/day	• Production goals were met and in some cases exceeded. • MGA with MBE: ~ 33 line km/day • MBE: ~ 50 line km/day • SSS/SBP: ~ 42 line km/day

Table 2. Performance objectives (continued).

Performance Objective	Metric	Data Required	Success Criteria	Results
Qualitative Performance Objectives				
Ease of use		• Feedback from technicians on usability of technology and time required to set up and operate. Feedback regarding difficulty in data processing.	• Ability to deploy the system efficiently and in a consistent manner • Smooth data processing workflow • Data analysis techniques allow for quick and accurate target identification	• Field operations encountered routine minor technical difficulties but operation was otherwise only limited by survey vessel maintenance, adverse weather, and/or sea state. • Software development and methodologies allowed incoming data to be processing rapidly. • Target picking from the gradiometer data was simple but full integration with acoustic data not completed.

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5.0 SITE DESCRIPTION

The demonstration site at South Beach is located along the southern shoreline of Martha's Vineyard, MA. The demonstration survey area extended approximately 4.3 km along South Beach, beginning approximately 200 to 375 m offshore at a water depth of approximately 3 m and continued out approximately 4.6 km offshore to a water depth of approximately 20 m. The length of this area along the shoreline corresponded to the terrestrial and surf zone area previously investigated as part of a preliminary assessment/site investigation conducted by EOD Technology, Inc. as well as areas to the east where munitions were previously found. Data from this investigation were used to help determine likely areas for deposition in the marine environment beyond the surf zone. The approximate demonstration area is shown on Figure 4.

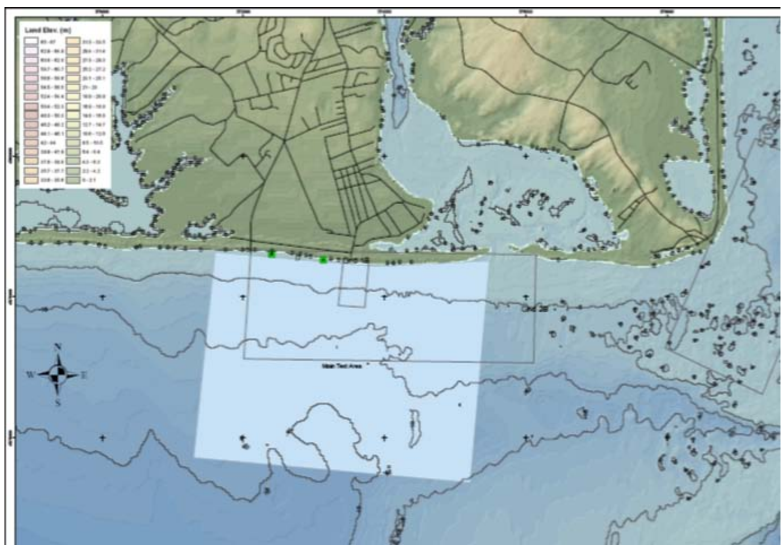

Figure 4. Approximate demonstration area.

5.1 SITE LOCATION AND HISTORY

In 1943 the Department of the Navy leased approximately 264 acres for training purposes, including the South Beach area. South Beach was known as the MTMGR for the U.S. Naval Air Station at Quonset Point, RI. This range was used for land-based machine gun training and machine gun and rocket target practice by aircraft. The Navy constructed an oval-shaped rail track to transport moving targets used on the range and a small observation/spotting bunker. At some point prior to 1946, the oval rail track was substantially destroyed by a hurricane. The Navy constructed new stationary targets at each end of the former track and began using the site for aerial bombing practice. Between 1946 and 1948, the Navy relinquished control of the site back to the prior owners.

While the range was originally constructed near the shoreline, it is now located approximately 150 yards seaward of the beach due to extensive erosion that has occurred since the range was built in the 1940s. A 1952 aerial photograph shows the remnants of the oval track along the shoreline and effects of erosion that had already erased the southern edge of the track (Figure 5 left). The right side of Figure 5 shows a modern aerial image of the south beach area where the oval-shaped track is only partially visible.

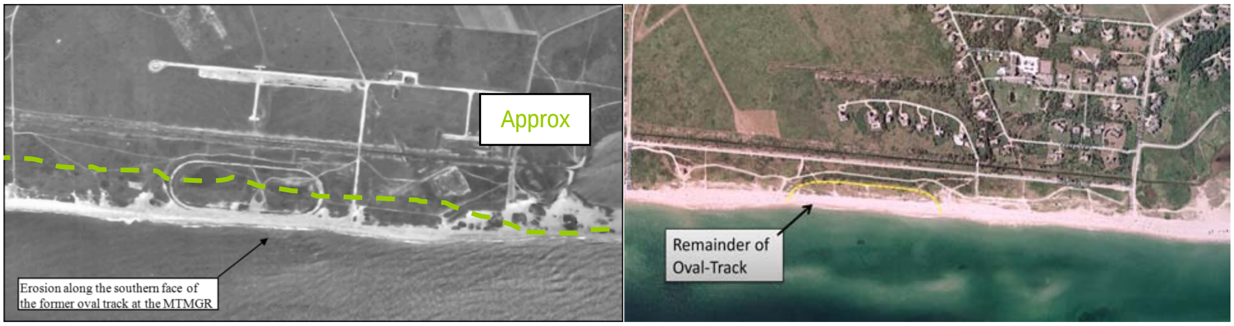

Figure 5. 1952 aerial photo (left) and modern aerial image (right).

5.2 SITE CHARACTERISTICS

The relatively flat ocean bottom at South Beach was ideal for the demonstration. The local geology was also expected to be relatively benign and not produce excessive interference (such as magnetic volcanic rocks). Furthermore, the sandy bottom proved forgiving to the MGA when a winch operator error resulted in a sub-sea collision with a sand dune.

Little information was known about the specific ammunition types and munitions fired or dropped at the former range. Assumptions regarding the potential MEC items present have been derived from the nature of the items found along the beach over time as reported in historical documents provided by the U.S. Army Corps of Engineers (USACE). In 1988, the U.S. Army and Navy conducted clearance operations in the former range area, where more than 1650 potential MEC items were found.

Most MD items were in the form of shell debris ranging in size from 2.5 to 5 inches in diameter and from 6 to 18 inches in length. Ninety-nine items were inert warheads. Although at the time of the MATEC report in 2003, no ordnance had been reported since the clearance, a representative of the Edgartown Parks Department indicated that he generally observes up to a dozen pieces of MD (target rockets are approximately 5 inches in diameter and range from 3 to 5 ft in length) every year along the beach. In addition, MEC has been found at both South Beach and at Wasque, located to the east, since 2003. It is not known whether this MEC is related to historical operations at South Beach. No specific marks or mods are available for the MEC/MD found because the items have been highly weathered in the marine environment and no firing orders for the range are available.

6.0 TEST DESIGN

6.1 CONCEPTUAL TEST DESIGN

Development of the demonstration design began with the preparation of a preliminary CSM that identified the site features of interest, primary sources, secondary source areas, and the types of MEC anticipated. The CSM was based on available historical evidence and mechanisms that may have shifted MEC within the survey area or to areas outside of the survey area boundaries.

Features of interest included the locations where MEC or related materials were most likely deposited as a result of firing or disposal. Secondary sources were the areas where MEC or related materials may have been deposited by the primary release mechanisms or as a result of movement via tides and currents based upon the documented history of the site and available oceanographic data. The types of MEC potentially present in specific areas were defined based upon the results of the shoreline/surf zone removal action conducted by VRHabilis under contract to the USACE in the summer of 2009, as well as historical documents provided by the USACE. The WAA evaluation strategy was developed based on the types of MEC potentially present in the study area, the amount of MEC anticipated, and the potential location and distribution of residual MEC.

As for many munitions response projects, a phased approach was used to promote efficiency and focus resources in the potential higher hazard areas. At the most basic level, the demonstration survey was designed to delineate the general area of impact associated with historical munitions activities at South Beach. However, the work was also designed to demonstrate the capability of the methodology for use in the identification of higher hazard areas where characterization and remediation efforts should be focused for maximum benefit (referred to as “footprint reduction”).

All three phases of the demonstration used the MBE, MGA, SSS, and SBP technologies, with the exception of Phase 3 during which SSS and SBP data were not collected. Detailed instrument specifications are discussed Section 6.3 and in the demonstration report (TtEC, 2011).

In the first phase of the demonstration, data were collected along a series of transects oriented approximately parallel to the shoreline within the established project boundaries. Cross line transects were run at a rate of 1 per 10 regular data collection transects for quality purposes (Figure 6).

Figure 6. Transects layout for marine surveys.

In the second phase, areas with higher magnetic anomaly densities were identified and a second series of transects was used to further evaluate these areas. The Phase 2 transects bisected the initial transects (Figure 6). Data from existing cross lines were used to evaluate the quality of the supplemental data; new cross lines were not necessary.

At the end of Phase 2, the MGA data indicated that the seaward extent of metallic debris off South Beach had not yet been determined. Instead of further bisecting identified high-density areas, Phase 3 supplemental transects were surveyed seaward of the initial site boundary to evaluate the potential seaward extent of the metallic debris (Figure 6).

The first step of each phase was to conduct a high-resolution MBE survey. The MBE data were primarily used to locate any obstructions that might pose a hazard to the MGA. The detailed bathymetric map generated from the MBE data was also used to search for cultural deposits proud of the bottom.

The initial MBE survey was followed by a combined MGA and MBE survey. The MGA provided magnetic field strength and magnetic field gradient data that were analyzed to identify potential MEC. The additional MBE data resulted in a higher density MBE data set, with no reduction in efficiency or quality of MGA data acquired.

A combined SSS and SBP survey was conducted as the final element of Phases 1 and 2. This survey provided SBP data to evaluate sediment stratigraphy and potentially identify depositional areas where MEC items may have become buried under shifting sediment. The SSS data were used to help identify features detected in the other data sets. Initial data processing and production of draft products were performed within 48 hours of data acquisition. Final data processing was performed following demobilization from the project site.

6.2 BASELINE CHARACTERIZATION PREPARATION

Field operation preparation for this project included the installation of an IVS for use in system function tests. The IVS was installed near the Edgartown Harbor rather than at the project site, as the harbor provided a more protected environment for both placement and survey of the IVS. Since the survey vessel was moored in Edgartown Harbor nightly, placing the IVS just outside the harbor allowed confirmation of system function while transiting to or from the survey area. The IVS was designed using a number of inert items found at South Beach as well as smaller unexploded ordnance (UXO) and surrogate targets.

The terrestrial RTK GPS base station used for the WAA was set up near Edgartown and was checked daily. The control point utilized is documented by the National Geodetic Survey with the Point ID “LW4271.” The RTK GPS base station correction was verified daily utilizing a control point with published coordinates located near the harbor. All survey data and control were referenced to North American Vertical Datum (NAVD) 83 MA Island, U.S. survey feet, Vertical Datum NAVD 88, or Mean Lower Low Water, Epoch 1993-2001.

6.3 DESIGN AND LAYOUT OF TECHNOLOGY AND METHODOLOGY COMPONENTS

Each component of the WAA survey system was described in Section 3.1. To avoid redundancy, this section will focus solely on the operational specifications of the MGA. Please see the demonstration report (TtEC, 2011) for the other systems’ specifications and refer to Figure 2 for the system integration diagram.

6.3.1 Magnetometer Array

Magnetometer surveys were performed using the MGA, a scalable, modular array containing seven sensors and having a physical swath width of 4 m. The array was configured using 1 m horizontal spacing between each of the four lateral magnetometers, with 0.75-m vertical and 1.2-m along-track separation. The array was towed at an altitude of approximately 2 m above the seafloor. The MGA was set to sample at 2 hertz (Hz), which provided somewhat reduced noise and improved small target detection relative to the 4 Hz setting. The MGA was operated from and towed with a 34 ft aluminum-hulled survey vessel (the R/V Ugle Duckling) configured with a winch and A-frame (Figure 7). The MGA was fitted with an acoustic transponder and was tracked with a vessel-mounted USBL. For redundancy, the position of the MGA was also calculated using layback with data provided from an instrumented sheave.

Figure 7. MGA mounted on TtEC vessel.

6.3.2 Calibration

Several functional calibration procedures were performed to ensure proper operation of the instrumentation in the selected configurations. These calibration procedures are discussed in the demonstration report (TtEC, 2011). All calibration processes relate to systems installation offsets and performance validation.

6.4 FIELD TESTING

The MBE and MGA systems were used in all phases of the demonstration; the SSS and SBP systems were used in Phases 1 and 2 only. Each phase was described in Section 6.1; a schedule is presented in Figure 8.

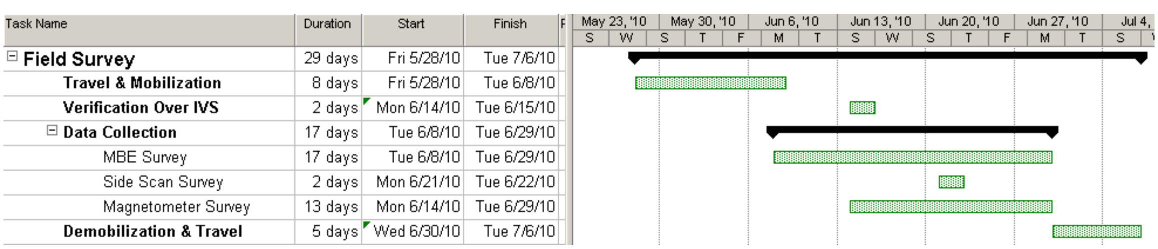

Figure 8. Schedule for field data collection (May–June 2010).

Date	Activity Log Summary	MGA Survey	MB Survey	SB/SS Survey	Vessel Repair	IVS	Systems Mobilization	Demobilization	Weather
6/2/2010	Vessel Mobilization						Y		
6/3/2010	All personnel and vessel on site. Visual inspection of IVS area. MB installed.						Y		
6/4/2010	USBL installed on vessel. Multibeam Patch test performed.						Y		
6/5/2010	Attempt pre-IVS MGA survey, cross-talk in system						Y		
6/6/2010	Rewire MGA tow bridal, test bridal, still cross talk						Y		
6/7/2010	MGA cross talk fixed. Complete pre-IVS survey. Begin phase 1 MBE survey.		Y			Y			
6/8/2010	Begin MGA survey of phase 1. Vessel Transmission failure.		Y						
6/9/2010	Vessel down for repair. Equipment testing maintenance and data processing.				Y				
6/10/2010	Install new transmission in survey vessel				Y				
6/11/2010	MBE and MGA survey	Y	Y						
6/12/2010	MBE and MGA survey	Y	Y						
6/13/2010	MGA survey, trouble with winch, place buoys to make IVS deploy location	Y	Y						
6/14/2010	Test winch while divers place IVS. MB IVS, no new data from south beach					Y			
6/15/2010	Survey IVS with USBL, survey IVS with MGA, new MB patch test					Y			
6/16/2010	combined MGA MB survey at south beach phase 1	Y	Y						
6/17/2010	Mobilize and test SS/SB						Y		
6/18/2010	combined MGA MB survey at south beach phase 1	Y	Y						
6/19/2010	Combined MGA MB survey phase 1 followed by MB phase 2 operations	Y	Y						
6/20/2010	SS/SB survey of IVS, conditions too bad to survey at south beach								Y
6/21/2010	SS SB survey at south beach ph1			Y					
6/22/2010	SS SB survey at south beach ph1			Y					
6/23/2010	MB survey phase 2		Y						
6/24/2010	Vessel maintenance. Process data and splice connectors for new tow cable.				Y				
6/25/2010	Replace vessel turbo charger, data processing				Y				
6/26/2010	MGA and MB survey south beach phase 2	Y	Y						
6/27/2010	MB survey phase 2 followed by combined MGA/MB survey phase 2	Y	Y						
6/28/2010	MGA/MB of IVS					Y			Y
6/29/2010	Post IVS removal survey					Y			
6/30/2010	Transmission Failure, demobilize				Y			Y	
7/1/2010	Transmission Repair, demobilize							Y	

Figure 8. Schedule for field data collection (May–June 2010) (continued).

6.5 DATA COLLECTION AND PROCESSING PROCEDURES

This section focuses solely on the MGA, the primary MEC detection technology, due to space limitations. Please see the demonstration report (TtEC, 2011) for a description of data collection and processing procedures for the other systems (MBE, SSS, and SBP).

6.5.1 MGA Data Collection

MGA survey operations for South Beach were conducted beginning on June 11, 2010. Prior to the survey, all pre-survey calibration and quality control (QC) operations were completed to ensure collection of consistent, high-quality data. The survey was conducted in accordance with the project-specific technical specifications provided in the approved Work Plan (TtEC, 2010).

The MGA geophysical survey was conducted along the same transects established for the bathymetry survey, allowing the MGA to collect data while ancillary systems tracked the boat and MGA in real time. The MGA was towed behind the survey vessel and the MGA position was tracked with the USBL (Figure 9). MGA position was provided to the HYPACK software, where navigation and sensor data were integrated, recorded, and displayed in real time. For positioning redundancy, an instrumented sheave was used to monitor cable payout and calculate the towfish layback.

Figure 9. MGA towing operation: preparation (left), surveying (right).

Marine Magnetic SeaLink software was used to configure and monitor the MGA. At the start of each survey session, sensors were time synchronized and configured to sample at 2 Hz. After deploying the MGA, manual tuning was applied to the sensors to obtain the highest sensitivity within the earth's ambient magnetic field strength at the survey location. For the South Beach survey, a tuning value of 54,000 nanoTesla (nT) was applied. SeaLink provided a real-time graphical display of the magnetic field strength data, as well as multi-axis gradients between the MGA sensors and the analytic signal. The raw MGA data were also recorded in SeaLink as a backup to the data stored by HYPACK, to store additional information for debugging the system, if needed.

The MGA survey area and line configuration was the same as that used for the MBE survey, which was described in Section 6.1. The swath width for the MGA survey was approximately 4 m, resulting in substantially less coverage as compared to the MBE. Table 3 contains a summary of the data quantities for each phase of the MGA survey, along with the average vessel speeds and data densities, that will be discussed in the following section.

Table 3. Data collection summary for the MGA survey.

Survey Phase	Transect Distance Surveyed (km)	Average Swath Width (m)	Area Surveyed (sq. km)	Hectares	Average Vessel Speed (kph)	Mean Sample Separation Distance (m)
1	236	5	1.18	118	6.3	0.88
2	29.6	5	0.14	14	7.0	0.98
3	20.1	5	0.10	10	6.3	0.87
Cross lines	11.4	5	0.06	6	6.3	0.87
Total	**297.1**	**5**	**1.48**	**148**		

km – kilometer m – meter kph – kilometer per hour sq. km – square kilometer

The mean sample separation distances for the MGA survey during the various phases of work are presented in Table 3 above. The number of samples collected per meter varied in relation to vessel speed and was consistently within the parameters established in the approved Work Plan.

MGA survey data were collected over a total area of approximately 1.48 sq. km. These data were processed in accordance with the methodology described in Section 7.1 to yield 761 anomalies with analytic signal anomalies 3 nT or greater. The final data were input into a Geographic Information System (GIS) where all survey data could be analyzed as a whole to identify potential MEC and make other determinations regarding site conditions.

6.5.2 MGA Quality Checks

Prior to the survey, all applicable pre-survey calibration and QC operations discussed in Section 6.3 of the demonstration report (TtEC, 2011) were completed to ensure detection and positioning systems were functioning properly. In addition, a series of physical checks was routinely conducted on the data collection system prior to beginning the survey work each day or periodically during the survey, as necessary. The final component of QC was the performance of real-time monitoring by system operators and automatic monitoring by software modules used for data collection.

QC checks for the MGA included static tests and daily testing over the IVS. A static test was conducted daily to evaluate the MGA for system and external noise sources while the array was being towed in a background area free of metal. The system was allowed to collect data for 1 minute; test data were then reviewed to ensure the standard deviation of the measurements about the mean was not excessively large (not greater than 1 to 2 nT).

Daily during data collection activities, the MGA was towed over the IVS or other stationary magnetic targets to evaluate function, accuracy, and repeatability. The data collected were promptly processed and analyzed in accordance with the procedures described in Section 7. Each day’s IVS data were compared to other data sets and a confirmation was made that quality data were being collected.

Data review and monitoring methods used for measuring data quality during MGA survey operations were similar to those described for the MBE survey. Real-time monitoring by operators, automatic monitoring by software modules and data review procedures were all used to ensure proper equipment performance. Because the MGA is towed astern of the vessel, it was critical that the operator monitor the USBL to ensure proper operation. Real-time quality assessment was performed by comparing the USBL reported position to calculated layback position, which should agree within a few percent, except where cross currents occur.

Product QC was applied during the data processing operations. The data were reviewed a second time as they were processed and edited. The final quality assessment for the data sets was conducted with Geosoft’s Oasis montaj mapping and processing software.

6.6 PERFORMANCE VALIDATION

The survey plan included validation of selected targets by UXO-trained divers, who would physically locate and identify the item that created the magnetic anomaly, determine whether they were MEC, and record their findings.

Unfortunately, at the time of this report no data were available from the diver investigation, which was performed by VRHabilis LLC divers and managed by UXB International Inc., the USACE New England District contractor performing remedial investigation (RI)/feasibility study (FS) work on Martha's Vineyard. As a result, our performance validation relies on the results of the IVS.

6.6.1 INSTRUMENT VERIFICATION STRIP

An area northeast of Edgartown, MA, was selected for the IVS location and a pre-survey was conducted on June 7, 2010. The IVS location was situated en route to the South Beach survey area; the IVS was deployed on June 15, 2010.

Due to limited visibility and the IVS design, the divers failed to place the entire IVS within the bounds of the pre-surveyed area. Fortunately, a survey with the MGA after the IVS was removed revealed that the IVS targets were not placed atop any major pre-existing magnetic anomalies. After deployment of the IVS, a diver carrying a USBL transponder determined the location of each IVS item. The diver moved from item to item, stopping at each item for approximately 1 minute. The IVS was surveyed once per day on each day MGA data were collected. In total the IVS was surveyed seven times, although not all components of the IVS were surveyed each day.

6.6.2 IVS Data Analysis (Small Target Detection)

The ability to detect small targets largely depended on the proximity of the sensor to the item. With limited ability to laterally guide the MGA precisely over individual IVS items, the items cannot be equally examined outside of a lab environment. Analysis was performed on the IVS data by examining individual survey passes of the MGA. The track of the starboard array on line 506_1407 on June 28, 2010, is shown in bold in Figure 10. The perpendicular ticks denote the sample locations taken every 0.5 second. The array passed close to three of the IVS targets and had a measurable response to each.

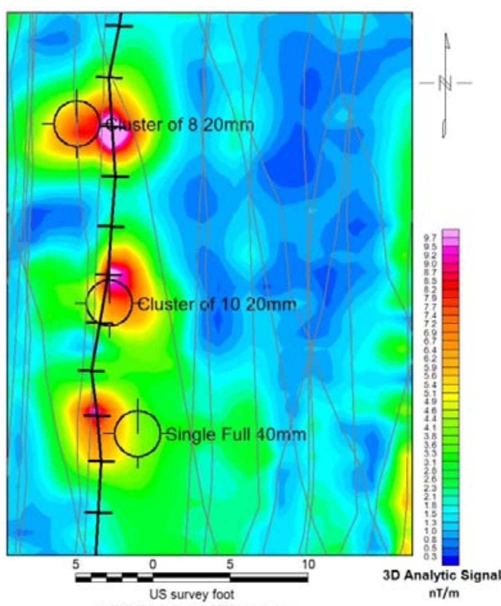

Figure 10. Close examination of three small IVS items.

Additional non-project-specific analysis of the IVS data was performed for the smaller IVS items that were emplaced in the IVS, in addition to six inert items that were recovered from the South Beach site during the time-critical removal. The design of the small item IVS was flawed in that many of the items were too close together to be resolved individually. This was especially true for the pipes at the ends of the IVS that were used to anchor the string to the bottom. The small item string was only completely surveyed twice, on June 15 and 28, 2010, to save time and maximize data collection out at the South Beach site. The results for the 15 and 28 June surveys, as well as the subset of items surveyed during the other days that the IVS was surveyed, are included in Table 5-5 of the demonstration report (TtEC, 2011).

In Geosoft's Oasis montaj, the analytic signal data from each day was gridded with a 0.6-m cell size. Peaks were selected from these gridded data using the "UXPKNESS" utility, which mathematically analyzes the peaks of the grids and writes the peak coordinates and magnitudes to a database. MGA altitude at the target pick location was also stored in the database. In Oasis montaj, the distance from the grid peak to the "known" position of the target based on the USBL survey was measured. From these data the maximum analytic signal strength (grid peak) for each target for each day was plotted (refer to Figure B-6, Appendix B, and to Table 5-7 and Table 5-8 of the demonstration report [TtEC, 2011]).

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7.0 PERFORMANCE ASSESSMENT

MGA data processing and analysis are discussed in this section; data products are included in Appendix C of the Final Report. For details on MBE, SSS, and SBP data analyses, please refer to the demonstration report (TtEC, 2011).

7.1 MGA DATA

7.1.1 MGA Data Processing

As noted earlier, the MGA was composed of two, three-axis gradiometers. In total, the MGA had seven magnetometers, and the two gradiometers shared the central magnetometer. MGA data were processed as two separate gradiometers flown side by side. The MGA generated time-stamped total field measurements (one for each of the seven magnetometers in the array) along with a set of ancillary measurements for each of the two gradiometers (altitude, depth, roll, pitch, and heading). Sets of difference values, or gradients, between selected pairs of sensors were extracted during processing. Each array was processed to derive vertical, horizontal, and longitudinal gradients, which were combined to form a 3-D analytic signal. The gradient and analytic signal data provided improved resolution and positioning of targets of interest when compared to positions derived from total field alone.

The .raw files collected in HYPACK contained all of the separate, time-stamped components of the MGA survey. These files were first processed with TtEC's MagProc software, which merges the total field data with time coincident attitude, altitude, heading, and position data to determine the XYZ position of each sensor at the time of measurement. If necessary, the USBL positions recorded in HYPACK were edited in NavEdit, a separate TtEC application, prior to being merged with the magnetometer readings. The MGA sensor measurements were projected into the local coordinate system in MagProc. The program also computed and georeferenced the gradient and analytic signal data for each of the two arrays. MagProc displayed total field readings from each sensor and all three axis gradients in profile (Figure 11) and output two file types, one with the total field and positional data for each sensor, and one that included the calculated gradient and analytic values and corresponding array positions (Figure 12).

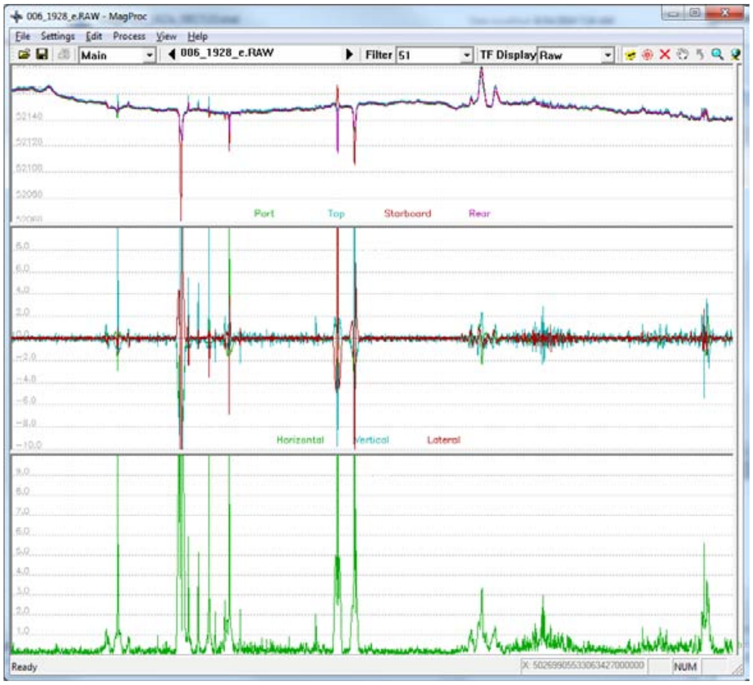

Figure 11. MagProc software display.

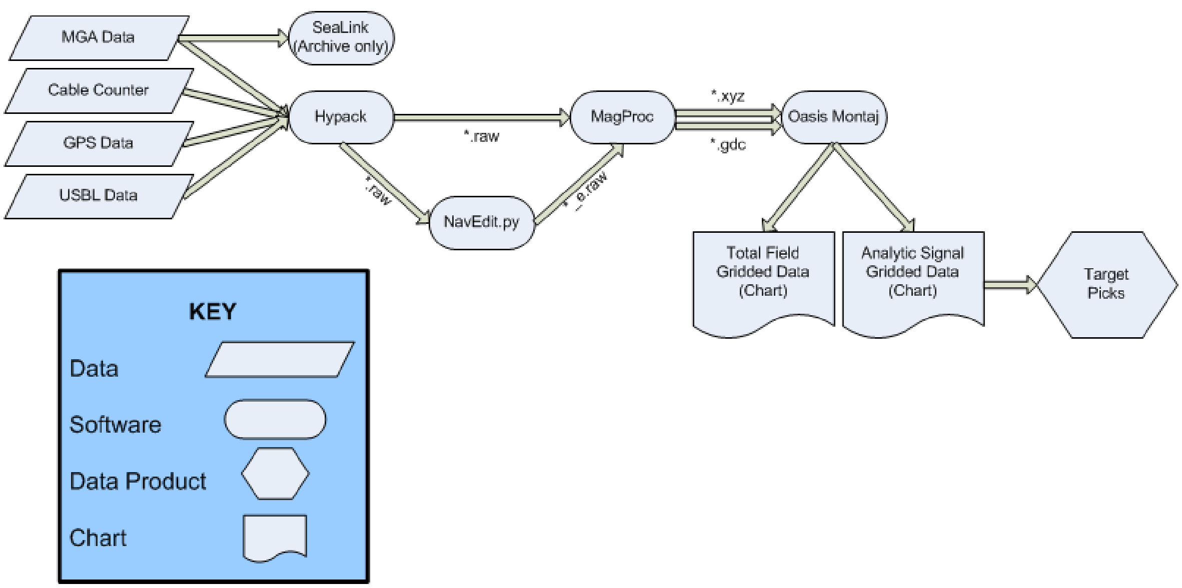

Figure 12. MGA data processing workflow.

These output files were then processed using Geosoft's Oasis montaj software, in which the data were filtered with a moving box car filter to eliminate magnetic field drift caused by diurnal variation. The data were then gridded to highlight regions with anomalous magnetic field strength, or in case of the analytic data regions, with anomalously high magnetic field gradients. Oasis montaj provided a set of tools for automatic selection of magnetic dipoles and manual and automatic detection and processing of targets. The automatic target picking algorithms were set with thresholds that were representative of the targets of interest. IVS survey results provided the necessary guidance for the target picking algorithm.

7.1.2 MGA Data Analysis

MGA data were analyzed visually to identify anomalies based upon dipole reading, size, and shape. These anomalies were then compared to automated target picks obtained during data processing with the Oasis montaj software (refer to Section 7.2). Selected targets were then plotted and their distribution was assessed visually. Anomaly distribution can provide clues to the origin of the anomalies. For example, a linear string of anomalies located along the western edge of the survey area and oriented perpendicular to the shoreline was interpreted to be a nonhazardous, cultural feature such as a communications cable. A second, semilinear cluster of anomalies located in the southeastern portion of the demonstration area was interpreted as potential MEC located along an approach lane for the western historical aerial target. The magnetic anomalies may also represent cultural debris that has been redeposited by currents and shifting sands and may or may not include MEC. MEC and fragmented cables or pipes have potentially similar transport and redepositional characteristics. If the ferrous targets were larger in size and higher in density than the sand, these items may have become “trapped” in topographically low features and transported away from their original point of deposition through the forces of gravity and water currents.

Both the total field magnetic data and the 3-D analytic signal data charts were presented in Appendix C of the Final Report, Plate 1, Sheets 2 and 3, respectively.

7.2 TARGET SELECTION FOR INSPECTION

MGA and corresponding MBE and SSS data were evaluated to determine whether anomalies were potentially MEC. Initial targets were selected using the UXO Detect module in the Oasis montaj software. Magnetic anomalies with a signature 3 nT or more above the background readings were selected; a threshold of 3 nT was based on magnetic anomalies measured in the IVS. The MGA analytic signal data (geotiff) and MGA target picks (dxf) were imported into SonarWiz for review with the SSS imagery. The SSS imagery was carefully reviewed at each magnetic anomaly, as well as overall for anomalous features that were not detected by the MGA. All anomalies, magnetic, acoustic or both, were denoted as contacts and a target report was generated in SonarWiz that included information about the anomaly (dimensions, type of contact) as well as a subset image of the SSS data in the vicinity of the anomaly. To augment this report, subsets of the gridded MGA data and an along-track profile of the magnetic anomaly were included for all contacts with a magnetic anomaly. The target report was used to determine which targets warranted further investigation. For example, magnetic anomalies that lay proud of the bottom (i.e., visible in the sidescan data) could be selected for diver or remotely operated vehicle investigation. The target report for all Phase 1 lines where quality MGA and SSS data were available is included in Appendix D of the Final Report.

7.3 PARAMETER ESTIMATES

Parameter estimation was not performed as part of this demonstration survey. The magnitude of the magnetic anomaly is a function of its size, shape, orientation, and exact distance from the sensors, none of which are known. When performing a WAA survey, the MGA is not likely to pass directly over the target generating the magnetic anomaly, and thus the actual target location may have some unknown lateral offset from the track of the MGA. Furthermore, the target may

be buried at some unknown depth that is not compensated for even when corrected for flight height. A small number of MGA targets were visible in the SSS data. These targets were measured (length, width, and height above the bottom) in SonarWiz.

7.4 CLASSIFICATION

7.4.1 Target Classification

Target classification was primarily a process of target reduction. The MGA detected ferrous objects, all of which potentially represent MEC. By assessing the pattern of magnetic anomalies with targets identified in the SSS data, the data analyst was able to classify some percentage of the magnetic anomalies as nonhazardous cultural debris. No confirmation of target classification was available.

7.4.2 Bottom Type Classification

Bottom type classification was performed on the SSS and MBE imagery data using Quester Tangent's QTC SWATHVIEWTM software, which processes raw backscatter data from MBE and SSS systems to generate maps of seabed type. A description of the classification process and results were presented in Appendix C, Plate 1, Sheets 5 and 6, respectively, of the demonstration report (TtEC, 2011).

7.5 DATA PRODUCTS

MGA data products are discussed in this section. For details on MBE, SSS, and SBP data products, please refer to Appendix C of the demonstration report (TtEC, 2011).

7.5.1 MGA Data Products

MGA data were gridded and exported to a GIS-compatible raster image. All MGA data and documentation are included in this report. All figures generated from the MGA data are presented in Appendix C of the Final Report.

7.6 DETECTION OF FEATUES OF INTEREST

Features of interest included historical aerial bombing targets (east, west, and old bunker), the range safety fans for the targets (east, west, and old bunker), and a potential disposal site on the eastern edge of South Beach. It was determined during the demonstration that these features were primarily located in very shallow water areas that could not be mapped without re-configuration of the detection and location systems. The areas could also only be surveyed during flat calm conditions due to complex sand bars within the near shore area. Since the intent was to demonstrate a WAA methodology, time and effort were not spent in adapting the systems for these very shallow water areas.

7.7 TIMELY INITIAL DATA PROCESSING AND MAPPING

Initial data processing and mapping were consistently conducted in a timely manner and in accordance with the performance specifications for the project. Preliminary analyses and plots

were used to plan follow-on work (i.e., identifying features in the MBE that might damage the MGA) and for evaluating general quality of performance. Initial quality evaluations supported slight adjustments to equipment configuration or operation that ensured that performance objectives were met.

7.8 GOOD PRODUCTION RATE

Production rates for the demonstration were very good and in general exceeded the performance criteria for the project. Although production rates can be greatly influenced by sea state and site conditions, the rates achieved during this demonstration illustrated the tremendous capability of the systems used in the performance of WAA for underwater munitions. Production rates for the various surveys are presented in Table 4.

Table 4. Summary of production rates.

Survey Phase	Average Production Rate (km/hr)	Average Production (hectares/day) assuming ~6 hours survey	Comments
MBE	6-10	50-600 (4-30-m water depth)	Hectares per day depends largely on water depth.
MGA	6.3	~22	Swath width is a fixed 5 m.
SSS	9	~260	Swath width for this survey was ~100 m.
SBP	9	NA	SBP generate 2D profiles thus area calculations are not applicable. Production is ~ 72 line km.

7.9 EASE OF USE

The detection and positioning systems used for the demonstration proved to be relatively easy to deploy and operate by an experienced field team. TtEC staff has developed efficient operational methods and the TtEC custom survey vessel contributed greatly to success of the demonstration, with custom mounting brackets for all necessary geophysical equipment and minimal mobilization time onsite. Because the vessel is only 8.5 ft wide and 34 ft long, it can be transported by trailer with relative ease and minimal cost anywhere in the nation without wide load permits.

The MGA is easily disassembled and transported in rugged cases that can ship on two pallets or individually by FedEx or similar carrier to any location in the world. When assembled, the MGA is 4 m wide and weighs just over 230 kilograms in air. Because the MGA is 1.5 m wider than the survey vessel, custom mounts on the A-frame were developed to cradle the MGA during transit from moorage to the survey site; this allowed the vessel to transit at its maximum speed. The A-frame was equipped with two hydraulic winches for lifting the MGA, which can be launched and recovered with just two people, although three provide for a quicker and smoother operation, especially in higher sea states. Figure 13 shows the sequence of recovering the MGA onboard the vessel.

Figure 13. MGA sequence of recovery.

8.0 COST ASSESSMENT

8.1 COST MODEL

As required by the project work plan, the cost assessment for this demonstration was based upon instrument costs, mobilization/demobilization, site preparation, survey costs, and data detection and discrimination costs. Cost elements and tracking are summarized in Table 5. A description of the costs elements is provided in the following subsections.

Table 5. Summary of cost tracking elements.

Cost Element	Data Tracked	Demonstration Costs ($k) and Other Details
Instrumentation cost	Equipment development, in-house pre-ESTCP demonstration (estimated)	$150
	Capital equipment purchases (MBE, SBP, SSS, MRU, RTK GPS, USBL, MGA, survey vessel, tow winch, acquisition/processing software, etc.)	$1200
	Lifetime estimate for electronic equipment	3-5 years
	Lifetime estimate for survey vessel	5+ years
	Lifetime estimate for electronic equipment	3-5 years
Mobilization and demobilization	Cost to mobilize and demobilize equipment and personnel to/from site, as well as costs to setup instrumentation and prepare and install/remove the IVS. Derived from actual demonstration costs	$95
Site preparation	Establishment of survey control. Note IVS installation costs are included with mob/demob costs.	N/A – provided by USACE
Field survey costs	Hectares surveyed – derived from actual MBS/SSS/SBP/MGA area surveyed	MBE = 738 hectare SSS = 814 hectare SBP=N/A, 2D profile MGA = 148 hectare
	Cost per hectare – derived from actual demonstration field survey costs and includes work plan preparation, mobilization/ demobilization, data processing, and reporting costs	MBE = $0.8/hectare SSS = $0.9/hectare SBP = N/A, 2D profile MGA = $2.1/hectare MBE/SSS/SBP/MGA = $2.5/hectare
	Hours per hectare – derived from actual demonstration production rates	MBE = 0.02 hrs/hectare SSS = 0.02 hrs/hectare MGA = 0.27 hrs/hectare SBP=N/A, 2D profile MBE/SSS/SBP/MGA = 0.31 hrs/hectare
	Personnel required	MBE = 2 hydrographers plus vessel captain SSS/SBP = 2 geoscientist plus vessel captain MGA = 2 geoscientist plus vessel captain

Table 5. Summary of cost tracking elements (continued).

Cost Element	Data Tracked	Demonstration Costs ($k) and Other Details
Detection and discrimination data processing and reporting costs	Total processing and reporting cost – derived from actual demonstration processing and reporting costs to date. Cost per hectare as function of anomaly density	$33
	Processing time required	120 hours
	Personnel required	Experienced (1) midlevel hydrographer and/or geophysicist to edit MBE/SSS/SBP/MGA data. Senior level (1) hydrographer and/or geophysicist MBE/SSS/SBP/MGA to review processing results, final data and anomalies. Principal/Senior level hydrographer and/or geophysicist with programming experience to develop custom scripts.

8.1.1 Instrumentation Cost

Instrumentation costs for this demonstration included equipment development, which was invested prior to funding being provided by ESTCP. These costs were estimated and included capital costs, including TtEC labor costs, for development and field testing of the MGA. These costs did not include the cost for Marine Magnetics to modify their commercially available SeaQuest that was adapted to create the custom-designed MGA used for the demonstration. The capital cost of the demonstrated software, sonar, positioning, and geophysical systems and 34 ft research vessel were approximately $1.2 million.

8.1.2 Mobilization/Demobilization Cost

These costs were based on actual demonstration costs and included mobilization and demobilization of equipment and personnel from their point of origin (primarily Seattle, WA) to and from the project site on Martha’s Vineyard. This category also summarized costs associated with the setup and preparation of instrumentation, including initial onsite RTK GPS quality assurance (QA)/QC, and support of the USACE diving contractor to install and remove the IVS at Martha’s Vineyard.

8.1.3 Site Preparation Cost

No costs were incurred under this category because the USACE established the survey control points used as control for the RTK GPS base station and QC of the RTK GPS rover.

8.1.4 Field Survey Cost

Costs and production rates associated with MBE, SSS, SBP, and MGA assessment methods were summarized by total hectares surveyed, cost per hectare, and hours required to survey a single (1) hectare. Each cost and production rate was summarized by assessment system (i.e., MBE, SSS, SBP, and MGA). Cost per hectare was based on actual total costs incurred during the duration of the field survey which included daily IVS survey costs, survey production time costs, vessel maintenance costs, weather downtime cost, and onsite preliminary data processing costs.

Hours per hectare were calculated using only hours in which MBE, SSS, SBP, and MBE data were acquired at the South Beach site.

8.1.5 Detection and Discrimination Data Processing and Reporting Costs

A summary of data processing methods and data products was provided in Sections 6.0 and 7.0. Their costs were based on actual processing and reporting costs.

8.1.6 Ground-Truthing Cost

A full marine WAA should also include sampling to support and verify sediment type classification and diver or remotely operated vehicle (ROV) sampling of selected sensor targets. The cost of these operations will vary significantly with the site and specific methodology employed.

Bottom type classification may be performed with some combination of sediment sampling (e.g., Van Veen, box corer, petite ponar, power grab, vibracorer), visual inspection by drop camera or ROV, or the use of data from other sources. In the case of this survey, sampling for seabed classification was not included in the scope of work so no actual costs can be provided.

The cost of diving operations can vary widely depending on water depth, with greater depths requiring both more time to get the diver to the target and much less available bottom time due to nitrogen intake. Dive operations in support of WAA ground-truthing at Martha's Vineyard were conducted and paid for by the USACE. Actual costs for these operations were not provided to TtEC.

8.2 COST DRIVERS

Cost drivers for underwater munitions assessment performed with the systems and methods described in this report are highly site-specific. This site- and project-specific items and conditions may include, but are not limited to, the following:

- Access to the work area (nearby boat ramps or marinas, cranes and slings, etc.)
- Daily transit distance from marina or daily launch site to project area
- Weather and time of year at which the WAA will be conducted
- Water conditions including tidal range, currents, flow rates (rivers), and sea state
- Range of water depths within survey area
- Bottom conditions such as rocks, coral, vegetation, and man-made features (intake structures, dams, piers, piling, etc.)
- The presence of endangered or threatened species
- Satellite coverage for navigation
- Size and type of vessel required (seagoing vessel versus small boat)

- Preconfigured vessel mobilization/demobilization or vessel of opportunity charter and mobilization/demobilization
- Size, quantity, and anticipated distribution of clutter objects and munitions.

While the technology is adaptable and applicable at most project sites, site conditions may make the technology more or less expensive for application at some sites. Sites that have a wide range of water depths will require that the systems be reconfigured during survey operations to allow data collection in very shallow water as well as deeper water areas. Sites with many hazardous bottom features such as rocks or man-made piers and pilings will be less accessible for survey and pose a greater hazard to the equipment, vessel, and personnel. As a result, survey operations at these sites may be slower and less fluid than at other sites.

8.3 COST ANALYSIS AND COMPARISON

The systems and methods demonstrated combined multiples types of sonar and magnetometer technologies, which simultaneously acquired geophysical data along a common survey transect. This method consolidated mobilization/demobilization efforts and survey teams and reduced the total number of survey passes necessary to acquire common datasets, resulting in a reduction in overall cost. Cost is always an important consideration and factor in the design and execution of a MEC WAA, so this method provides a substantial benefit to projects.

When compared to other similar MEC survey approaches and technologies, the demonstrated production rates, as presented in Table 5, exceeded terrestrial man-portable carts, vehicle-towed array, and marine-towed array production rates. These production rates were provided at a cost substantially less per hectare than these other types of terrestrial and marine survey methods. The per hectare cost and production rates for the sonar systems were similar to those achieved by helicopter array survey methods. The MGA acquired data with a detection sensitivity that exceeds helicopter arrays (isolated BDU-33 or 2.75-inch warheads were the expected lower detection limit for the airborne Multi-sensor Towed Array Detection System [MTADS]). Analysis of seed items (105 mm, 81 mm, and 60 mm) showed 100% detection of 105 mm items, 85% of 81 mm items, and 66% of 60 mm items (McDonald et al., 2005) and is near, as determined by IVS (see Tables 5-5 and 5-7 of the demonstration report [TtEC, 2011]) the detection rates of vehicle-towed arrays. (The MGA repeatedly detected a single full 20 mm round in the IVS, as well as the 40 mm. The TtEC vehicle-towed array can detect 20 mm rounds to 6-inch depths reliably, and other systems even deeper as the sensors are placed closer to the ground surface.) Terrestrial MEC systems can collect up to four hectares a day at a cost of $5000 to $7400 per acre. Further, data comparable to aerial LiDAR, black-and-white aerial photogrammetry, and seismic reflection data were also provided within the per hectare price for the WAA.

9.0 IMPLEMENTATION ISSUES

Installation of the IVS proved one of the most difficult activities for the demonstration. While TtEC has developed several methods for placing seed items in the IVS and for maintaining their installed positions, currents, tides, and even curious boaters make it difficult to install and maintain an IVS throughout the life of a project. Better methods for anchoring the IVS seeds and markers will need to be developed, or the IVS process will need to be replaced with other QC procedures such as remapping transects or grids to demonstrate system performance. Other implementation issues are discussed in the following subsections.

9.1 REGULATIONS AND PERMITS

In the state of Massachusetts, any marine geophysical data collection requires a permit from the Massachusetts Board of Underwater Archaeological Resources. The special use permit for the RI/FS at various locations at Martha's Vineyard (Chilmark, Edgartown, and West Tisbury), MA, was issued as Special Use Permit No. 10-003 for the RI/FS and this demonstration. No other permits were required.

9.2 END USER CONCERNS

End user concerns are primarily related to the survey technology and methods. Underwater surveys for munitions are relatively new and end users are awaiting definitive proof that the new technologies and methods are effective. The South Beach demonstration provided dependable evidence that the types of systems used and the data collected are reliable and provide consistent useful data for remedial planning at underwater munitions sites. The ability of the various systems to detect and accurately position targets and features of interest was verified by the IVS survey. In addition, data from various surveys collectively supported the conclusions drawn from individual surveys. Sand dunes and shoals observed in the MBE data were also noted in the SSS and SBP data. Each survey supported and strengthened the findings of the other surveys. Finally, the QC checks and calibrations performed during the demonstration clearly showed that the systems were reliable and accurate. Points on cross lines correlated well with corresponding points on the survey transects and data from remapped lines compared favorably with the original data.

9.3 CURRENT AVAILABILITY OF THE TECHNOLOGY

All the systems used in the demonstration were off-the-shelf commercial products or were crafted by making modifications to commercial products to make them better suited and more cost efficient for the task of finding underwater munitions. System integration and software development are ongoing; however, the systems employed for the demonstration have now been used at multiple project sites for assessment of underwater munitions and are at a relatively mature state at the present time.

9.4 SPECIALIZED SKILLS AND TRAINING

The general mechanics of system deployment and operation do not require a high level of training. System tracking and data collection require education in the technical principles of each system and real-time experience with system setup and operation to acquire good quality data. Education, training, and experience are necessary for data processing and interpretation,

particularly for the MGA data. Manual interpretation of this type of data is art as well as science—qualitative as well as quantitative. The size and shape of anomalies, and the relationship of those criteria to known criteria for munitions of interest, play as big a part in the selection of targets as do the nT readings recorded by the magnetometers.

10.0 REFERENCES

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APPENDIX A

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